Technologies to Improve Water Management for Rice Cultivation to Cope with Climate Change

Chwen-Ming Yang*

Taiwan Agricultural Research Institute, Wufeng, Taichung 41362, Taiwan ROC

ABSTRACT

To ensure available food supply to meet the food requirements of the world's growing population, future crop production must be increased under the pressure of limiting global water resources. However, precipitation patterns become more erratic and frequency of extreme weather events will be increased under current climate change scenarios, thereby causing a greater uncertainty on freshwater supply for agricultural uses as well as to the performance of crop productivity. Even worse, it may give rise to regional water deficiency and/or generate water shortage in a period of time. Without sufficient water for irrigation, there is pressing need to betterment of water resource management so as to increase water productivity of agricultural sector. Fortunately, since various water resources are used, such as rainfall, surface water or groundwater, in different types of agriculture (i.e., dryland, rainfed and irrigated) to a variety of crop species, there exists wide scope and potential for the improvement. Strategic planning of water supply for demand and variety improvement for stress tolerance are also strategies that can be adopted as supplements. Rice is the staple food for the people live in the Asia and Pacific region, where nearly 90% of its production is consumed locally in most countries. As the lifeline of the people, demand for rice is expected to grow faster than production. Yet, there is signal indicating the yield deceleration and stagnation observed in some high-yield environments. The reduced resource trend and the deteriorating environment impose further threats and limits. Nevertheless, because of the complexity with incompatible changes of involved factors, different views considering available approaches of water management for improving water-use efficiency (WUE) and increasing rice production have evolved, particularly in favorable rice ecologies. In addition, climate change brings about further impacts and challenges to all aspects of rice production. This paper highlights the impacts and challenges brought by climate change that threaten to rice productivity and production, but also introduces technologies and practices that may be applied for rice culture with smart water use bridging the gap among countries/regions of unequal resources and uneven constraints by climate change.

Key words: Water management, Water use efficiency, Rice production, Climate change, Technology.

因應氣候變遷提升稻作栽培水分管理之技術

楊純明*

行政院農業委員會農業試驗所

摘要

為確保世界人口增長所需要的糧食供應，未來農作勢必要求能夠在全球有限水資源狀況下增加生產。很不幸的，依照現行氣候變遷情境的發展，降水型態將更加紊亂失序而無規律，極端天氣事件發生頻率也將愈來愈高，大大提升了農業灌溉淡水供給量的不確定性及農作生產效率的表現。尤有甚者，亦將因此產生區域性的缺水情況，或帶來短期的供水短缺。由於灌溉水量的不足，

* 通信作者，cmyang@tari.gov.tw

投稿日期：2012 年 9 月 5 日

修正日期：2012 年 9 月 20 日

作物、環境與生物資訊 8:193-207 (2012)

Crop, Environment & Bioinformatics 8:193-207 (2012)

189 Chung-Cheng Rd., Wufeng, Taichung 41362, Taiwan ROC

將使得水資源的管理更為重要，才能改進農業的水分生產效率。所幸農業灌溉用水取自於不同水源(如降雨、地表水、地下水)，操作於各式農耕系統(如旱田耕作、雨灌耕作、灌溉耕作)，且施用於各種需水量的農作物，因而存在多樣的、不等的改進空間。此外，亦可透過策略性灌溉規劃及耐逆境品種改良等的配合作為輔助措施，來增加農作的水分利用效率。稻米為亞太地區居民的主食之一，許多國家甚至消費其自有生產量的 90%以上。作為當地最重要的糧食根源，未來將可能因為人口的增長，造成對稻米的需求超過生產幅度，但是跡象卻顯示有些高產的水稻生產區已呈現生產量停滯或下降現象。如果再加上資源趨於短蹙，農業環境逐漸惡化，則糧食供給前景堪慮。有見於此一複雜而負面的因子干擾，有識之士已著手研擬各種可能的水分管理方案，試以改進水分的利用效率及提高稻米產量，特別注重於善加利用有利的生態環境。這樣的解決方案在當前氣候快速變遷之下尤顯必要，因為氣候變遷對許多已知生產層面都會帶來不等程度的衝擊與影響，亟待因應處理。本文將據此予以突顯問題所在，使讀者瞭解其等對水稻生產力與生產量的可能影響，同時介紹針對水分管理的可行技術與措施，以更有效能的使用有限的水資源來生產稻米，並冀望能夠因而減縮因為資源與限制條件的不對等所造成的生產差異。

關鍵詞：水分管理、水分利用效率、稻米生產、氣候變遷、技術。

INTRODUCTION

Rice is estimated to feed up to more than 40 million people around the world daily. For the most people live in the Asia and Pacific region, rice is the staple food and nearly 90% of its production is consumed locally in the region. The belt from Pakistan in the west to Japan in the east is the major zone of rice production and consumption. Rice also constitutes the major economic activity and is a key source of employment and income for the rural population within the region (Facon 1999). Actually, rice self-sufficiency and rice security accounts for food self-sufficiency and food security in the majority of the Asian countries (FAO 2004). As the lifeline of the people, demand for rice is expected to grow faster than production due to a rapid increase in population (Swaminathan 1998). It has been prospected that more than 800 million tonnes of rice will be needed annually by 2025, an additional 300 million tonnes per year to be produced at conditions of less resources, such as land, water, pesticide and labor (Hossain 1997, Barker *et al.* 1999). However, there has been the signal indicating the yield deceleration and production stagnation observed in some high-yield environments (Papademetriou 1998).

This paper will highlight the threatens of water scarcity and drought, and will also reiterate the importance of efficient water management for rice production and the urgent need in taking actions to solve the underlying problems in regarding to food security and water security.

WATER SCARCITY

Water scarcity is expected to be one of the largest societal and environmental problems worldwide in the near future, so water use by natural and agricultural ecosystems has become a central subject in research as well as social agendas (UNDESA 2012). Vegetation of crops has been recognized to be vulnerable to the negative effects of climate change, particularly in terms of increasing intensity and recurrence of dry periods (IPCC 2007). Under current scenario of climate change, irregular climate, erratic precipitation patterns and increasing frequency of extreme weather events will further magnify their extent. Additionally the negative effect is reinforced by a parallel increase in global temperature which will alternately deteriorate the effects of drought. The empowered impacts pose profound influences on current cultural practices and crop productivity and also attract public attention seeking to cope with the prospected situations.

Importance of Water for Crop Production

More people are aware of the importance of water as a limiting factor for the future crop production, which should be included as a priority in the planning of crop production

systems (Aranda *et al.* 2012). In any case, despite the constraints of water scarcity and others, increase of rice production over the next generation is required in order to meet the food needs of Asia's poor. Producing more rice with less water is therefore an unshirkable responsibility and challenge for global food, economic, social and water security (Facon 1999).

To obtain better results, both farmlands and forest plantations should be put into consideration for management in a sustainable manner on the basis of their water consumption and water availability. These two types of land use consume water and provide avenues for saving and storing water as well. Basically, the capacity of a field crop to cope with water scarcity is conditioned by the many factors affecting water use that are species specific (Oren *et al.* 1999a, 1999b), and to the growing status of crop such as population size, planting density and growth stage (Granier *et al.* 2000, Moreno and Cubera 2008). These factors affect water balance of the crop and can be controlled and considered in the adaptive crop management (Bladon *et al.* 2006, Gyenge *et al.* 2011). The practices that manipulate their influences offer opportunity and potential for managing water use more efficiently.

In this paper, measures and technologies to improve water efficiency and productivity of rice at all levels, including field, farm, district (system), river basin and watershed, are particularly emphasized. As it is foreseeable that rice will be produced in a water scarce environment in the future, technologies to save water and measures for efficient water management should be the principal concerns in agronomy and breeding program. A broad scope in considering a basin-wide or watershed perspective would result an integrated concept and a total solution to the situations, for which it requires policy, economic and institutional reforms and incentives for farmers willing to adopt. Such an approach is truly feasible and workable and be used to narrow the gaps between countries/regions having uneven resources and development levels.

Wide Adaptability and Resilience of Rice

With wide adaptability to varying soil and nutrient status, rice is grown on broad spectrum of environmental conditions. Rice plants are also capable in facing and dealing with harmful environment to a certain degree. Nevertheless, biotic and abiotic stresses resulted from adverse conditions impose constraints to plant growth and cause heavy yield losses under severe cases. It therefore requires appropriate strategies and technologies to ameliorate such situations. With improved crop management technologies and varieties, suitable farming prescriptions can be programed for specific situations or even for individual farmlands.

Although rice may not be the agricultural product that uses the most water, some people argue whether rice should be grown in places where water is a limiting resource. As a matter of fact, in some countries like Australia and Taiwan, rice growing is the most regulated agricultural industry in terms of land and water use, policy and environmental impacts. Overall water availability for irrigated rice and allocation of water for every designated area is determined by state governments or local irrigation associations and is monitored very closely. In Australia, rice is grown in rotation with other crops such as wheat, barley and corn, which utilized the existing soil moisture from the harvested rice crops without a further irrigation. In many rice production districts of Taiwan, rice is rotated with upland crops (e.g., corn, soybean sweet potato and green manure crops) and vegetables. This type of practice allows for additional water savings and more efficient water usage.

As a whole, availability of water supply is one of the significant constraints to rice production and the main cause to yield variability (Yeston *et al.* 2006). Saving water in rice-based irrigation systems needs particular attention because of the mass amounts of water pumping to growing rice and the increasing demand by other sectors. Further, there are numbers of factors that have an impact on the quantity and quality of freshwater for irrigation, particularly global population growth, economic development and the current climate change trend. Understanding the factors affecting water resource management is important for efficient water use as well as for sustainable development of rice ecosystems. For this reason, scientists from rice-produced countries are encouraged to work together as well as to collaborate with farmers to find ways to continue producing 'more rice with less water.'

Rice Production in Water Scarce Environment

More than 97% of water resources on earth are in the oceans and seas not available and suitable for most agricultural production uses, and only one-thirds of the remainder is freely to use. Of about 108,000 billion m^3 precipitates onto the earth's surface, approximately 60% evaporates directly back into the atmosphere. However, water availability varies across continents, with Africa, Asia and Europe watered less. Owing to heavy seasonal rains, much of Africa and Asia's potential supply is lost through runoff (Seckler 1993). Because lack of adequate water and irrigation infrastructure, not enough water is available for irrigation during dry seasons. Over the recent years, the scarcity of and competition for water have been increasing worldwide, while the opportunities for developing new water resources for irrigation are limited.

In fact water is the single most important component for sustainable rice production, especially in the traditional rice growing areas of Asia-Pacific region. Indeed the link between water and rice is crucial because rice is a labor-intensive crop that also requires plenty of water. Its cultivation is mainly under rainfed conditions in places receiving plenty of rainfall, while irrigation is still prevailing in areas with advanced watering infrastructure. As increase production of rice is one way to meet demands of increasing population, efficient water management and water use become a primary issue to drought-prone regions or countries where water is a limiting resource to agriculture. Recently more rice-producing countries are facing water scarcity now than ever before, it should be aware of reducing water use or enhancing water use efficiency in order to sustain rice production in the long run.

Rice is the dominant irrigated crop, accounting 30% or more of the total irrigated area and taking up nearly 70% of water in irrigated agriculture, which has traditionally consumed more than two-thirds of the available water supply for agriculture, in many Asian countries (Barker *et al.* 1999), including Taiwan. As the demand for domestic, industrial, municipal and other uses rises, less water will be available for agriculture in the future (Rosegrant *et al.* 1997). More percentage is projected to decline in developing countries. If food security is to be maintained, in addition to find ways of reallocation of water among competing uses, approaches of increasing the water productivity must be considered and implemented as top priority. Major changes in practices, policies and institutions will be required to ensure an appropriate management of the limited water resources for increased water productivity (Rosegrant *et al.* 1997, Hamdy *et al.* 2003). Above all, investments have the right of way. Investments should be placed on not only constructing new watering infrastructure but maintaining the existing irrigation and water supply chains to meet the growing demand for water in all aspects. Efforts for mitigating the impact of water scarcity on and water withdrawals from agriculture and non-agricultural sectors are also important. The coping changes in policy and institutional support should follow timely.

WATER CONSUMPTION AND WATER MANAGEMENT

In some countries of Asia, Farmers' Association or governments can help farmers to set out plans for managing farm irrigation and improving water and soil management within the farm, district or landscape. In addition to enhance irrigation efficiency, these plans may also provide other applicable measures to be incorporated as an integrated farm management for long-term farm operation so as to preserve the farmland for sustainable uses. In this respect, government plays a significant role in providing policy and institutional support.

It is strongly suggested that water management should be viewed from a systematic view. The issues and problems associated with water productivity at different farming levels need to be discussed altogether so as to improve efficiency of water management. In many cases several strategies and/or technologies will be required to improve the productivity of water use in either irrigated or rainfed agriculture (Wang *et al.*, 2002). Breeding strategy certainly is the one cannot be ignored, better management of the water resource and changes in crop management are also strategies should not be neglected. None of these strategies should be seen as operating in

isolation. Rather, it is likely that the greatest gains will be obtained through complementary approaches involving each of them.

Water Management — From a Broader View

Water is consumed during the production processes of rice crop, yet large range of climates generate a variety of hydrological regimes and an uneven distribution of water resources and water use conditions. Significant achievements have been made in increasing rice yield during the past few decades, though serious gaps exist between potential and actual yields in many rice-producing countries. There is a need and potential to further increase the yields and narrow the gaps. However, not only factors that affect water use in rice production systems remain to be resolved, but the measures of water management to farmland should be renovated regularly.

To adapt to water scarcity, generally the following management measures are suggested. The rule of thumb is to consume less water, followed by modify water demands, maximize efficiency in water use, and improve the economic, technical and environmental performance of water consumption, together with diversification of production and cropping patterns, changes in management systems and structures, and financial and fiscal sustainability (Facon 1999). Moreover, make better levels of education and technological environment are also important constituting favorable conditions for an improvement of the irrigation schemes. On the other hand, the issue of rehabilitation, which in relevant to operation, maintenance and modernization of irrigation infrastructure, is equally important.

Water Management — Country-based Strategies on Degree of Water Scarcity

As previously mentioned, wide range of climates produce a variety of hydrological regimes and the uneven distribution of water resources. Few countries are categorized as absolute water scarcity, some have sufficient resources to meet future water demand, while more sensitive others need to increase certain extent of water resources development (Facon 1999). Although the nature and degree of the projected water scarcity vary around the areas, there is a general agreement that improvement of the performance of water management/irrigation systems is to delivering water to farm field in a more efficient, flexible, reliable and equitable manner.

In order to avoid water becoming a significant constraint in socio-economic development and to meet food security, some areas need to invest massively in both water development and improvement of irrigation systems. In this regard, four guidelines suggested by Ricegrowers' Association of Australia (2012) are worthy noting that provided for rice growers to be more water wise. These are: (1) rice can only be grown under strict regulations such as location, soil types and water availability; (2) shorter season rice varieties are the high choice so that rice is grown with less water; (3) plant crops require less water in the winter to utilize the remaining soil moisture from a preceding rice crop; (4) implement actions conform to the plans set out by the state/national governments to minimize irrigation impact on environments.

There are approximately about a quarter of the population live in countries or regions of absolute water scarcity in Asia, where severe consequences of water shortage bring substantial impact on agricultural sector and to both rural and urban living. For which places, governments need to assist people in finding solutions to continue agricultural production to meet their food demand and generating activities to support employment and income to achieve their food needs. It may also need to import cereals and non-staple food for the poor segments of the population. With regards to this context, nearly all countries need to investment on establishing a mixture of improved water resources supply and management scheme to increase irrigation efficiency and productivity ensuring nation's food security at emergency.

Water Management — Concerns of Farming Practices

Relative to other cereals, water demand for rice production is very high, particularly 'wet rice'. Strategies and technologies that can reduce water use in farming practices during the production processes are considered applicable for water management. The amount of water used for land

preparation is the most concern for water consumption in rice cultivation. It is not unusual that wetland preparation often supply more than adequate amounts of water to saturate the soil in the land soaking process as well as to maintain a submerged or muddy condition in facilitating the processes of ploughing, harrowing, puddling, and land leveling before seedlings transplanting. Land soaking in the beginning of the season is for dissolving cracked soils that resulted from soil drying during the fallow period after the previous crop. The water loss will be higher when land preparation is completed in a longer time. During the growth period, water usually is applied to the field at amounts much more than the actual requirement of crop, leading over water loss through surface runoff, seepage and percolation. Moreover, such as in Taiwan, most farmers prefer to maintain a relatively high depth of water in transplanted rice for purposes of weeds control and reducing labor cost by applying minimum frequency of irrigation, a practice increases percolation rate and causes surplus water loss. Based on such situations, accordingly, there is potential for increasing on-farm water productivity, by increasing yield per unit water use during crop growth, through approaches of reducing evaporation, seepage, percolation and surface runoff along crop growing period.

Improving management practices and infrastructure functions that result in enhancing water use efficiency or recycling water at downstream locations will also increase water productivity. Therefore, reducing the period of land preparation would lead to substantial savings in water. Using more field channels or waterways to distribute water in the field, instead of the field-to-field transport, can shorten the time and reduce water lost. The puddling process during land preparation to form a semi-impermeable layer with a low hydraulic conductivity is an effective way to reduce percolation during crop growth. Shallow and dry tillage after harvest that restrict the formation of soil cracks or impede water flow through the cracks can reduce bypass flow. Similarly, small soil aggregates produced by dry tillage can block the cracks and reduce amount of bypass flow. Maintaining a thin water layer for saturating soil or by alternating wetting and drying process could reduce water applied to the field compared with the traditional practice of continuous shallow submergence. Planting rice in the fields with shallow groundwater table can reduce irrigation frequency.

By the adoption of improved, early maturing, high-yielding varieties during past decades, the transplanted-rice system has increased the average yield and reduced crop duration and hence, improved water productivity in rice culture (Khush 1995, Chaudhary 1996). Early maturing character results in early harvest of the crop and reduces irrigation inflow. However, it requires extra water for growing seedlings and maintaining a shallow water depth in the fields prior to transplanting. In some countries, mostly in Southeast Asia, sowing seeds directly on rice fields have gradually replaced transplanted rice in recent years (Ho *et al.* 1993, Fujii and Cho 1996). The technology resolves partly the problem of farm labor shortage and reduces wages for transplanting operation as well. The shift from transplanting to direct seeding, particularly the dry seeding form, reduces the irrigation inflow for land preparation and improves water-use efficiency (WUE) in rice culture. The less water-use dry-seeded rice is to sowing ungerminated seeds on dry or moist but not puddled soil, while the wet-seeded rice is to sowing germinated seeds on wet or puddled soil (Bhuiyan *et al.* 1995).

Water Management — Concerns of Irrigation and Drainage

Because of the projected increases in population and food demand, as well as economic development, food production will need to increase substantially. As frequency of drought and extent of water scarcity are expected to increase under climate change scenario, costs for irrigation will raise while available water resources for irrigated agriculture will be relatively limited. In most cases, priority is designated on meeting total society water demand for their socio-economic development. The problem would be greater for those countries with finite water resources and investment capacity.

While irrigation development dates back several centuries, the modern irrigation

development has been increased rapidly mainly in the twentieth century. A majority of the countries in the Asia and Pacific region have achieved self-sufficiency in cereal crops, mostly rice, while some countries cultivate paddy rice principally during the wet season and are not considered as irrigated fields. Nonetheless, rice is grown with traditional flood irrigation methods worldwide. That is, rice fields often remain flooded during the entire growing season. While this practice has proven successful for centuries, pre-planned irrigation methods are considered the preferred approaches since the availability of water for food production becomes more scarcity in the future.

In the humid regimes, frequently large amounts of water flow during a short period of time, particularly during the typical monsoon climate and wet season. Without flow regulations or in the absence of storage, flood occurs and flood control, not drainage, is the most concern for water management. In many cases, the situation arises when it is usually needed less. In the tropical zone, wet season irrigation is almost only paddy rice, but varieties of crops are grown under irrigation during the dry season (Hatta 1967). For most of countries, surface water is the prime source of irrigation water and groundwater is considered supplement because of electrical power requirement for pumping water. Currently, rice represents about 45% of all irrigated crop areas in Asia and 59% out of it is irrigated. In the Far East, Southeast Asia and the Islands, the figure may go up to more than 90% (Facon 1999). The need and usage of drainage become more and more popular and needed.

Drainage is closely linked to irrigation in most of the region, though water flows from one field to another in terraced paddy cultivation and no difference between irrigation and drainage. In humid zones, however, the main purpose of water control in lowland or wetland is to ensure water level and drainage to prevent floods. In arid and semi-arid areas, drainage infrastructure is associated with irrigation for purpose of effective irrigation. The objectives of irrigation and drainage are to achieve self-sufficiency in crop production or to further exceed the rising populations. In the industrialized areas, tubes, channels and canals for irrigation and drainage should be distinct, using separate routes, to avoid contaminations with wastes from various sources. Due to increased competition for water by the rapid growth of other water use sectors, irrigation efficiency must be improved to keep pace with the trends. Some advanced countries have developed kinds of integrated water management programs in response to the concerns.

Water Management — Breeding Strategy, A Traditional Way

Genetic variability of a plant species is driven primarily by variability in the natural environment, and the challenge to research scientists is to confront such variability in characteristics of interest by genetic manipulations, through traditional genetic cross or modern genetic engineering. The purpose is to transfer genetic materials that express natural tolerance to either biotic or abiotic stresses, which are polygenically controlled. And the goal of this practice is to break the genetic ceiling (high peak) of the target characteristics to attain higher performance (Richards *et al.* 2002).

Different plant species have their distinct characteristics, such as growth behavior, reproduction pattern and lifespan, which also distinguish one species from the other in terms of water requirement and use. Therefore, different plant species must be treated in varied ways for water management. Rice is a crop that has been the focus of a long-standing breeding effort for higher WUE (Condon *et al.* 2004). With the prospected shortage of water supply for agriculture and growing rice requires plenty of water, there is a pressing need to improve the WUE of both rainfed and irrigated crop production than ever.

Breeding rice varieties with higher WUE provide a solution, at least partially. Three key processes which not independent of to each other have been summarized and be exploited in breeding for more efficient water use: (1) moving more of the available water through the crop rather than it being wasted as evaporation from the soil surface or drainage beyond the root zone; (2) improving crop transpiration efficiency by acquiring more biomass in exchange for the water transpired by the crop; and (3) partitioning more of the achieved biomass into the harvested product (Condon *et al.* 2004).

Although being greatly concerned by consumers, in coming to the era of rapid progress in plant molecular genetics, biotechnology and systems biology, we are probably on the border of breakthroughs in the ability to understand and manipulate plant responses to environmental stresses, including water scarcity. With the on-going research and progress, the breeding of new varieties with improved ability and capability to water scarcity become possible. These high tolerance varieties will facilitate water management program and perform better WUE and water productivity that enable rice adapt to environments under climate change. However, application of such varieties to the optimization of specific water management programs and water deficit episodes under field conditions may have to consider other stress factors, and hence, should be adopted with caution. Parallel measures to include supplementary strategies and technologies provide a more comprehensive solution to coping with rice production in the multifactor natural environment.

Water Management — Water Management Simulation Model

Models are a mathematical representation of a real world system. The use of models is now very common in diversified disciplines, including agriculture and environmental sciences. For a crop simulation model, it may integrate current scientific knowledge from many different fields, such as agronomy, crop physiology, plant breeding, agricultural meteorology, soil science, plant pathology, entomology and others. In general, an output can be calculated or predicted with the model as a function of crop species, vegetation growth and development, management scenarios, soil conditions and weather inputs.

Crop simulation modeling can be used to assess the likely impact on WUE and yield of changing the expression of traits of interest and hence, is both measure and tool suitable for improving efficiency of water management. Results of such simulations indicate that greater progress may be achieved by collecting traits so that potential negative effects of individual traits are neutralized (Condon *et al.* 2004). The impact of climate change on water management can also be assessed and evaluated through modeling. The outputs of the responses to impact and recommendations for adaption strategies are good sources for feedback adjustment of the implemented measures. Furthermore, appropriate strategies and technologies may be adopted get ahead of climate change from the results of modeling. In terms of irrigation planning, supplemental irrigation water could be supply in a more efficient way while excess amounts of watering would be reduced to the right manner.

Climate change in the long run may decrease crop yields and enlarge climatic risks to crop production with increasing abiotic and biotic stresses (Lobell *et al.* 2011). As concern in this paper, it will worsen water crisis to further limiting water supply for agriculture. Over the period of time we will need to enhance the use of water resources conservation technologies, increase the efficiency in the use of water resources, and make best use of less water for rice production. Use of crop simulation models would help in not only studying and evaluating impacts of climate change and water management on rice production, but also identifying and prioritizing the management strategies and technologies for adapting climate change and improving water management.

IRRIGATION EFFICIENCY VERSUS IRRIGATION WATER PRODUCTIVITY

Irrigation efficiency is a part of efficient water management, and is an engineering term used in irrigation science to characterize irrigation performance (Howell 2003). It is a critical measure to define the amount of water required for evapotranspiration (ET) divided by the amount of irrigation water diverted into a field (plot), farm, district (system), basin or entire watershed (Bos 1979, Heermann *et al.* 1990). The value of irrigation efficiency and its definition are important to the views of irrigated agriculture and its benefit in supplying the abundant high quality food supply required to meet population growth. It is also essential to evaluate irrigation water use in agriculture and to promote better use of water resources. In a broad sense, water withdrawals from irrigation water should include

seepage (S), percolation (P), runoff (R) and transpiration (T) aside from evaporation.

The efficiency of rice-based systems is less than 50% and is lower in the wet than in the dry season. It would seem that there is plenty of means for improving irrigation efficiency. However, in discussions of potential improvements to a rice-based system, the boundary of the targeted area should be taken into consideration. That is, the definition of efficiency will vary if it be at field, farm, irrigation system or even river basin/watershed. The responsive strategies and the factors to be considered for improving efficiency will also vary accordingly from level to level. Increasing efficiency at one level may not lead to greater efficiency at the next level up. For example, surface runoff, seepage and percolation at either field, farm or system level can be used elsewhere at the basin level from the viewpoint of wastewater reuse or recycling. Based on this premise, the practice of canal lining to save water is a negative way to reduce groundwater recharge, and lost water from one field but is recovered downstream resulting only in "dry" water savings (Seckler 1996). Thus, it is only useful to save water (real water savings) which would otherwise be lost to a non-useful sink (such as saline water body or the ocean).

However, moving from the field and farm to the system, basin and watershed levels, accounting for irrigation water use and productivity becomes more complex. Process depletion or the amount of water diverted and depleted to produce the rice crop may represent a relatively small portion of inflow. Consideration must be given to the consumption or depletion of irrigation water inflow, not only in crop production but in all other uses, outflow or costs. For example, wastewater recovery or recycling often involves an additional cost which should influence the water management options. Saving water does not necessarily lead to increased water productivity. Moreover, the efficiency concept gives little information about the amount of food that can be produced with the amount of water available (Howell 2003). In this respect, **irrigation water productivity**, which defined as the amount of food produced or the gross value of output per unit volume of water used, is a more useful term and solid concept (Viets 1962, Tabbal *et al.* 1992, Tuong and Bhuiyan 1997, Molden 1997). As with efficiency, in productivity assessment the boundary or level (farm, system, basin or watershed) must be clearly defined when making measurements. At basin or watershed level, benefits have to be looked at from a broad scope, such as hydropower generation, flood protection, instream uses and environmental considerations. Improving water productivity at the basin/watershed level therefore assumes a wider significance in managing basin/watershed water resources. Modern techniques such as Geographic Information Systems (GIS), Remote Sensing (GS), Global Positional System (GPS) and hydrologic modeling are suitable tools for planning and developing appropriate management strategies.

IRRIGATION TECHNOLOGIES FOR RICE – OPTIMIZING WATER EFFICIENCY

An adequate water supply is essential for plant growth. When rainfall is not sufficient, additional water supply in form of irrigation is necessary. Various technologies can be adopted to supply irrigation water to the plants (Tabbal *et al.* 1992, SWIM 1997). Each technology of irrigation has its advantages and disadvantages, the most suitable one will be that is best suited to the local circumstances.

A number of technologies/techniques have been developed for water management to improve water use efficiency. The impacts of climate change on freshwater systems and their management impose additional concerns, which have been summarized from the observed and projected phenomena, mainly increases in temperature, sea level and precipitation variability (IPCC 2007, Kundzewicz *et al.* 2007). For crop irrigation, optimal water efficiency means minimizing losses due to evaporation, runoff or subsurface drainage while maximizing production. Water used in irrigation is developed toward a conservative manner to save water, with particular emphases on coping mechanisms for crop plants in drought-prone environments (Neumann 2008).

Whatever irrigation technology is being chosen, its purpose is always to attain a better

water management and a higher yield. Therefore, proper system setup, construction and irrigation practice are of utmost importance. The maintenance of the system to keep it functioning is equally significant, but is often neglected. This always results in inferior irrigation efficiency and thus less benefit from the irrigation system.

Surface irrigation

Surface irrigation is the application of water by gravity flow to the surface of the field, either the entire field is flooded or the water is fed into small channels or strips of land (Brouwer *et al.* 1991, Holzapfel *et al.* 2009).

A. Continuous flooding

Continuous flooding is the commonly used practice in traditional irrigation for rice production, but is now regarded as water consuming. Quite often water is very uneven in distribution, either in excess or not sufficient. This technology is also called basin irrigation, because rice plants are grown in flat areas of land surround by bunds and can stand in wet or waterlogged condition in the flooded basin.

B. Furrow irrigation

Furrow irrigation is a simple irrigation technology to bring water from the source of supply. In modern society, generally water is pumped to the fields along furrows, which usually are small, parallel channels. Crop plants are normally grown on the ridges between the furrows.

C. Border irrigation

Border irrigation is the technology that uses earth bunds to divide farm fields as well as to guide water inflows down the field. It is more suited to the larger mechanized farms that have long uninterrupted field lengths for ease of machine operations.

D. The alternate wetting and drying irrigation

The alternate wetting and drying irrigation (AWD) has been launched for decades as a technology for water saving in growing rice and other crops (Kang *et al.* 1998). An integral tubing system in dissemination irrigation water in an efficient way is pivotal to the success of the technology, whereas production benefit and weeding effectiveness are two constraints to be solved by practicing this technology.

Overheading Irrigation

Overhead irrigation, which using center-pivot or lateral-moving sprinklers, has the potential for an equal and controlled distribution pattern. Water is pumped in under pressure and sprayed through an overhead network of pipes/guns/sprinklers down onto the plants from flat spray nozzles. The technique has been widely used in fields of upland crops and yet, is not restricted to apply in 'dry irrigation' for rice cultivation.

Drip Irrigation—Subsurface Drip Irrigation

Drip irrigation is the least-used type comparatively, but offers the ability to delivering water to plant roots with minimal losses and fess evaporation (Nakayoma and Bucks 1986, Burt and Styles 2007). Recent studies found that subsurface drip irrigation is a superior system for irrigating aerobic rice or varieties suited for drip based cultivation, especially when used together with fertigation. The combined approaches increase root volume, source capacity and translocation efficiency and thus, growth of aboveground plant parts. Subsurface drip irrigation is installed with low-flow-rate emitters operating at low pressures and could relatively alleviate the water deficit situations and also improve the uptake of essential nutrients. The technology has been suggested to be a valid alternative to conventional flood rice culture for varieties with high WUE, based on water savings and yield data (Ottis *et al.* 2006).

Deficit Irrigation

Deficit irrigation, by reducing irrigation water use, has been designated to cope with situations where irrigation supply is restricted (Chaves *et al.* 2007, Fereres and Soriano 2007). Despite deficit irrigation can be used as a strategic measure to reduce irrigation water use when supplies are limited, it is not known whether the technology can be used over long period of time. Research is encouraged to investigate the sustainability of deficit irrigation and to what extent it will last with minimum irrigation water use.

Others

Other irrigation technologies are also available to fit specific conditions, such as

growing rice in ways as upland crop, alternating with low water requirement of drought tolerant crops, precision irrigation, temporary fallow and flexible dates for planting, etc.

THE INTEGRATED WATER MANAGEMENT APPROACHES

Water management is very complex by itself. Problems involved are not only technological but also political and institutional, involving domestic and international affairs (Rice 1997). Identification of causes for the problems that impede to or responsible for the improvement of water management are the first step. Development of possible measures that suitable to problem solving and be bridging the gaps of management drawbacks is considered the second move (Fujisaka 1994, Duwari *et al.* 1998, Delmer 2005, Lobell *et al.* 2011). The Integrated Water Management (IWM) approaches are a collective way that suitable for a district, nation or a region, if it has been made appropriately and endorsed by consensus.

Although the most appropriate IWM packages to adopt will vary over time and space, the implementation requires participation of the practitioners, including farmers, system managers and some others. These packages will also require a multi-disciplinary approach and relevant strategies and technologies. Because of the involvement of all stakeholders and substantial investments, it will have to be designed carefully, with potential for future development. To avoid disappointment and disillusionment, one should be aware of prevention of the hasty introduction, contradiction to the existing environments, and conflict with cultural or socio-economic conditions. False start, uncertain initiatives and unnecessary attempt are incorrect matters that should be refrained from.

The Integrated Water Management, A Systematic Planning

These approaches require a systematic planning, including location-specific technologies plus active policy and institutional support from governments. Each of the IWM packages is accomplished by systematic studies to understand the causes and then to develop suitable management practices. Research and extension services play a significant role in linking together the related measures and technologies so that all related water use sectors are willing to adopt the same location specific IWM packages without contradiction to or the opposite of each other.

The location specific IWM packages will not just to improve water management but to 'prescribe' strategies and technologies used for water management, leading toward a form of "prescription water management". This will make the approaches acceptable and easy to be popularized. However, there is a need for setting up specific IWM packages that fitted to the specific locations because all nations are unique by themselves.

Constitutes and Concerns of the Integrated Water Management

Strategic planning and technical knowledge are important factors in determining the feasibility and adaptability of the adopted IWM, and whether it deserves to receive priority (Sinclair and Muchow 2001). Above all, the most significant criteria would be whether it is affordable and merit to adoption in bridging knowledge and technology gaps for improving water management. Also, the components of an IWM package are vital to maximize its efficiency, adaptability and profitability. Strategies and technologies that make use of lower cost with better profitability are more preferred, which can provide major incentives for farmers or growers to strive harder. Since each nation is conditioned in developmental levels and socio-economic status, the policy, institutional and technical support should also be taken into account. Workers and extension staff who responsible for operating and consulting the IWM program need to be trained well and be equipped with adequate knowledge and tools so that they can coordinate the program, educate their users, and provide technical support.

The efficient water management can be achieved to attain sustainable rice production and food security. The IWM acknowledges the complexity of a rice production system and further to include the related impact factors that must be managed to achieve the goal. An IWM package based on best management strategies and technologies can provide a solid framework for

applicable practices, along with the evaluation, input and output, of these management practices. All stakeholders may establish a collaborative networking to strengthen and betterment of the IWM program. A successful IWM program will lead to not only efficient water management but sustainable rice production and environmental conservation.

CONCLUDING REMARKS

Rice is vital to people live in the Asia-Pacific Region where 90% of the world's quantity is produced and consumed to support 56% of humanity lives (Huke and Huke 1997). However, the prospected demand for rice is outgrowing than the production in most countries. How to increase rice production for keeping up with the demand growth, while using fewer resources (e.g., land, water, manpower) and agro-chemicals, is a big challenge. One of the promising approaches is to improve water management to bridge the yield gap, by use of advanced strategies and technologies that are developed location specific. In addition, technology transfer and adoption in conjunction with manpower development are necessary elements supplement to the success, and has to be carried on by the local governments. Knowledge sharing and technology utilization across states facilitated by regional organizations or district cooperation will put on extra points and sometimes, is indispensable when resources and obligations are closely linked.

Irrigation is probably the largest single water consumer, mainly for food production. Restricted water resources and competition for water from other sectors will reduce the share of water for agricultural use. Agriculture sector is now face the era to manage water use under water scarcity. For rice crop, the total area is decreasing but the proportion of the rice area under irrigation is increasing. As the supply of irrigation water to rice cultivation will decline in the future, relative to the rising costs, demand from other uses and the contamination by agrochemicals, water productivity must be improved with reduced water used. Likewise, as the profitability of rice farming has being declining, each society should establish some kinds of incentives for farmers/rice growers and irrigation system managers to enhance performance and promote responsibility for operation and maintenance of the systems related to water management. Over the past decades, substantial gains have been achieved. The facts have revealed that, provided that the practitioners are empowered and equipped with adequate support and irrigation service plus the economic incentives, they would adopt the given measures in their water management practices.

From the viewpoint of sustainability, a hydrology-driven and rice-ecology-based approach in rice water management is the right direction to address the diversity of constraints in upland/rainfed and lowland/irrigated systems, where elongated droughts and increased floods alternately threaten rice fields (Hundertmark and Facon 2002, Tal 2006), particularly in trends of climate change (Lobell 2011). The location specific and socio-economic circumstances of rice ecology determine the degree of freedom for effective intervention in the water resource system and management scheme. Moreover, systematic views considering vary levels and measure options are complemented by a set of related strategies and technologies. With the flexibility and reliability, such an integrated water management approach should be the appropriate answer to rice water management that would provide a change to really improve irrigation efficiency and water productivity now and the future. Such intelligent approach merits the full attention of all stakeholders and is worthwhile to point out for development.

REFERENCES

Aranda I, A Forner, B Cuesta, F Valladares (2012) Species-specific water use by forest tree species: From the tree to the stand. **Agric. Water Manage.** (visit on 07/25/2012) http://dx.doi.org/ 10.1016/j.agwat.2012.06.024

Barker R, D Dawe, TP Tuong, SI Bhuiyan, LC Guerra (1999) The outlook for water resources in the year 2020: challenges for research on water management in rice production. *In*: International Rice Commission Newsletter No. 49. DV Tran (Ed.) Food and Agriculture Organization of the United Nations. Rome, Italy.

Bhuiyan SI, MA Sattar, MAK Khan (1995) Improving water use efficiency in rice irrigation through wet seeding. **Irrig. Sci.** 16: 1-8.

Bladon KD, U Silins, SM Landhäusser, VJ Lieffers (2006) Differential transpiration by three boreal tree species in response to increased evaporative demand after variable retention harvesting. **Agric. For. Meteorol.** 138:104–119.

Bos MG (1979) Standards for Irrigation Efficiencies of ICID. **J. Irrig. Drain. Div. ASCE** 105(IRI):37–43.

Chaudhary RC (1996) Internationalization of elite germplasm for farmers: collaborative mechanisms to enhance evaluation of rice genetic resources. p.221-243. *In*: Plant genetic resources: characterization and evaluation. MAFF, NIAR, JIRCAS. Tsukuba, Japan.

Condon AG, RA Richards, GJ Rebetzke, GD Farquhar (2004) Breeding for high water-use efficiency. **J. Exp. Bot.** 55:2447-2460.

Facon T (1999) Water Management in Rice in Asia: Some issues for the future. *In*: Proceedings on Bridging the Rice Yield Gap in the Asia and Pacific Region. October 5-7, 1999. Regional Office for Asia and the Pacific, FAO. Bangkok, Thailand.

FAO (2004) Rice is Life. Proceedings of the FAO Rice Conference. 2004. Special edition. Vol. 53. International Rice Commission Newsletter. Food and Agriculture Organization, the United Nations. Rome, Italy. (Visit on 07/14/2012.) http://www.fao.org/docrep/008/y5682e/y5682e00.htm

Fujii H, MC Cho (1996) Water management under direct seeding. p.113-129. *In*: Recent Advances in Malaysian Rice Production - Direct Seeding Culture in the Muda Area. Y Morroka, S Jegathesen, K Yasumobu (Eds.) Ampang Jajar, Alor Setar, Malaysia. Muda Agricultural Development Authority (MADA) and JIRCAS.

Granier A, P. Biron, D. Lemoine (2000) Water balance, transpiration and canopy conductance in two beech stands. **Agric. For. Meteorol.** 100: 291–308

Gyenge JE, ME Fernández, M Sarasola, T Schlichter (2011) Stand density and drought interaction on water relations of Nothofagus antarctica: contribution of forest management to climate change adaptability. **Trees Struct. Funct.** 25:1111–1120.

Hamdy A, R Ragab, E Scarascia-Mugnozza (2003) Coping with water scarcity: water saving and increasing water productivity. **Irrig. Drain.** 52: 3–20.

Hatta S (1967) Water consumption in paddy field and water saving rice culture in the tropical zone. **Japan Trop. Agric.** 11: 106-112.

Heermann DF, WW Wallender, MG Bos (1990) Irrigation Efficiency and Uniformity. p.125-149. *In*: Management of Farm Irrigation Systems. GJ Hoffman, TA Howell, KH Solomon (Eds.) Amer. Soc. Agric. Engrs., St. Joseph, MI, USA.

Ho NK, CM Chang, M Murat, MZ Ismail (1993) MADA's experiences in direct seeding. Paper presented at the Workshop on Water and Direct Seeding for Rice. June 14-16, 1993. Ampang Jajar, Alor Setar, Malaysia. Muda Agricultural Development Authority (MADA).

Howell TA (2003) Irrigation Efficiency. p.467-472. *In*: Encyclopedia of Water Science. New York, Marcel Dekker.

Hundertmark W, T Facon (2002) Options for effective rice water management. Part IV. In: Proceedings of the 20th Session of the International Rice Commission. Food and Agriculture Organization of the United Nations. July 23-26, 2002. Bangkok, Thailand. (visit on 08/20/2012) http://www.fao.org/docrep/006/Y4751E/y4751e0j.htm#TopOfPage

IPCC (2007) Climate Change 2007. Synthesis Report. Contributing of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, RK Pachauri, A Reisinger (Ed.) IPCC, Geneva, Switzerland. 104pp.

Khush GS (1995) Modern varieties - their real contribution to food supply and equity. **Geojournal** 35:275-284.

Kundzewicz ZW, LJ Mata, NW Arnell, P Döll, P Kabat, B Jiménez, KA Miller, T Oki, Z Sen, IA Shiklomanov (2007) Freshwater resources and their management. p.173-210. *In*: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. ML Parry, OF Canziani, JP Palutikof, PJ van der Linden, CE Hanson (Eds.) Cambridge University Press, Cambridge, UK.

Lobell DB, W Schlenker, JC Robert (2011) Climate Trends and Global Crop Production Since 1980. **Science** 333(6042):616-620.

Molden D (1997) Accounting for water use and productivity. SWIM Paper No. 1. IIMI, Colombo, Sri Lanka.

Moreno G, E Cubera (2008) Impact of stand density on water status and leaf gas exchange in Quercus ilex. **For. Ecol. Manage**. 254:74–84.

Neumann PM (2008) Coping mechanisms for crop plants in drought-prone environments. **Ann. Bot.** 101:901-907.

Oren R, N Phillips, BE Ewers, DE Pataki, JP Megonigal (1999a) Sap-flux-scaled transpiration responses to light, vapor pressure deficit, and leaf area reduction in a flooded *Taxodium distichum* forest. **Tree Physiol.** 19:337–347.

Oren R, JS Sperry, GG Katul, DE Pataki, BE Ewers, N Phillips, KVR Schäfer (1999b) Intra- and interspecific responses of canopy stomatal conductance to vapor pressure deficit. **Plant Cell Environ.** 22:1515–1526.

Papademetriou MK (1998) Current issues of rice production in Asia and the Pacific. Paper presented at the 19th session of the International Rice Commission. September 7-9, 1998. Cairo, Egypt. 18pp.

Ricegrowers' Association of Australia (2012) About Rice. How much do you know about the Australian rice industry? Find all the facts here. (Visit on 7/12/2012.) http://www.aboutrice. com/index.html

Richards RA, GJ Rebetzke, AG Condon, AF van Herwaarden (2002) Breeding opportunities for increasing efficiency of water use and crop yield in temperate cereals. **Crop Sci.** 42: 111–121.

Rosegrant MW, C Ringler, RV Gerpacio (1997) Water and land resources and global food supply. International Food Policy Research Institute (IFPRI), Washington DC.

Seckler D (1996) The New Era of Water Resources Management: From “Dry” to “Wet” Water Savings. Issues in Agriculture 8. IWMI Research Paper 1. The Consultative Group of International Agricultural Research. Washington, DC.

Swaminathan MS (1998) Issues and challenges in sustainable increased rice production and the role of rice in human nutrition in the world. International Rice Commission. April 4-2, 1998. Cairo, Egypt. 23pp.

SWIM (1997) Water saving techniques in rice irrigation. Report of the SWIM Mission to Guilin Prefecture, Guangxi Region, China. May 25-30, 1997.Smith AM, M Stitt (2007) Coordination of carbon supply and plant growth. **Plant Cell Environ.** 30:1126-1149.

Tabbal DF, RM Lampayan, SI Bhuiyan (1992) Water-efficient irrigation technique for rice. p.146-159. In: Soil and water engineering for paddy field management. Proceedings of the International Workshop on Soil and Water Engineering for Paddy Field Management. VVN Murty, K Koga (Eds.) Jan. 28-30, 1992. Asian Institute of Technology, Bangkok, Thailand.

Tal A (2006) Seeking Sustainability: Israel's Evolving Water Management Strategy. **Science** 313(5790):1081-1084.

Tuong TP, SI Bhuiyan (1997) Increasing water use efficiency in rice production: farm level perspectives. p.108-111. In: Proceedings of the International Workshop More from Less: Better Water Management. September 21-23, 1997. Department for International Development, Cranfield, UK.

UNDESA (2012) Water scarcity International decade for action 'Water For Life' 2005-2015. Depart of Economic and Social Affairs (UNDESA), United Nations. (Visit on 07/13/2012) http://www.un.org/waterforlifedecade/scarcity.shtml

Viets FG (1962) Fertiliser and efficient use of water. **Adv. Agron.** 14:223-264.

Yeston J, R Coontz, J Smith, C Ash (2006) A Thirsty World. **Science** 313(5790):1067.